Environmental and Technology Policy Options in the Electricity Sector: Interactions and Outcomes

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Economists generally advocate pricing emissions as the most efficient way to get greenhouse gas reductions.

Yet we observe a great diversity of policies — many of which are aimed directly at technologies — particularly renewable energy and energy efficiency, for which enthusiasm is greater.

Not clear to what extent intended as substitutes or complements — or how effective they are.
Smart people worry about this

Will Europe Scrap its Renewables Target? That Would Be Good News for the Economy and for the Environment

Posted on January 18, 2014 by Robert Stavins

The European Union is considering scrapping the use of binding renewable energy targets as part of its global climate change policy mix that will extend action from 2020 to 2030. The Financial Times reported that this move – presumably due to concerns over high European energy costs during the ongoing economic downturn – will “please big utility companies but infuriate environmental groups.” The International New York Times framed the story in similar ways.

About the Author
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Cost of abatement with renewables

\[
\text{Implicit carbon price} = \frac{\text{Net cost of renewables}}{\text{CO2 emission reduction}}
\]

Marcantonini and Ellerman (2013)
EU Targets

2020  2030

Emissions reductions (from 1990)  20%  40%

Renewables  20%  27%
(share of energy consumption)

Energy efficiency improvement  20%  ??
State Emissions Targets

Source: C2ES
Renewable portfolio standard

Renewable portfolio goal

www.dsireusa.org / March 2013

State RPS Programs

29 states + DC and PR have an RPS (8 states have goals)
Other State Policies for Renewables

- 3rd-Party Solar PPA (power purchase agreements) Policies
- Energy Efficiency Resource Standards
- Grant Programs
- Interconnection Policies
- Loan Programs
- Net Metering Policies
- PACE (Property Assessed Clean Energy) Financing
- Property Tax Incentives
- Public Benefits Funds
- Rebate Programs
- Sales Tax Incentives
- Tax Credits
Useful Distinctions from an Economic Perspective

• Fixed-price measures
  – Carbon tax
  – Fossil fuel taxes
  – Renewable subsidies

• Endogenous-price measures
  – Cap-and-trade
  – Portfolio standards
  – Performance standards
  – *Credit value adjusts to other market influences*
Combining Renewable Policies with a Cap-and-Trade System

- *With a binding cap, supplementary policies offer zero incremental emissions reductions.*
  - Boehringer and Rosendahl (2010), Fischer and Preonas (2010)
- Renewable energy subsidies cause allowance prices to fall
  - Tends to benefit dirtier emitters!
    - i.e., coal-fired save more than natural gas-fired
    - Less fossil energy generation overall
      - Displaced by RES-E
- Also cause electricity prices to fall
  - Lowers incentives for energy efficiency
- Raises compliance costs if no other market failures
Combining Policies with Tradable Standards

- A binding renewable portfolio standard links the fates of fossil and non-fossil energy
- Supplementary policies that lower the cost of renewables make credits cheaper
  - Benefits fossil energy suppliers
  - Expands overall consumption
    - and emissions! (unless there’s also a cap)
- Supplemental policies that burden fossil energy reduce demand for renewable credits
Rationales for Overlapping Policies
How many tools do we need?

- Economic principle: Need as many tools as problems
  - If GHGs are the only problem, an emissions price is the only tool needed; anything else raises costs
  - If renewable energy share is only goal, then RPS by definition should be efficient

- Other market failures:
  - R&D, learning-by-doing spillovers
  - Network effects
  - Barriers and information problems
  - Credit access constraints
  - Market power
  - Energy security
  - Other underpriced emissions…
Multiple Market Failures

- Emissions externality
- Knowledge market failure – inability of innovators to appropriate all the gains
  - Spillovers from R&D and LBD
    - Jaffe et al. 2005
- Energy efficiency demand failure
  - Apparent undervaluation of EE investments
    - Gillingham et al. 2009
Our Research Objectives

Assess conceptually and quantitatively

- how multiple market failures interact and influence policy outcomes
- how policies interact
- to what extent these technology market failures justify overlapping policies
Approach to evaluating policies

- Analytical and parameterized numerical model
  - deliberately simple to capture key behavior
  - quantitative results illustrative rather than definitive
- Extensions to Fischer & Newell (2008; “FN”)
  - Richer description of nonrenewable supply curves
  - Distinct conventional and next-generation renewable energy technologies
  - EE investment and valuation rates
Basic Model

- Partial equilibrium model of electricity supply and demand with representative sectors
- Mature technologies
  - Coal
  - Natural gas
  - Nuclear (fixed in 1\textsuperscript{st} stage)
  - Hydro (baseload)
- Innovating technologies
  - Conventional renewable ("wind")
  - Advanced renewable ("solar")
Two Stages

• Stage 1 (2015-2020)
  – Production
  – Knowledge accumulation for renewables via R&D and learning-by-doing
  – Short- and long-run EE improvements

• Stage 2 (2020-2035)
  – Production
  – Cost-reducing knowledge application for renewables
  – Short-run EE improvement
  – With discounting, 2nd stage ~ 10 years
Knowledge Accumulation

- Stock $K(H_t, Q_t)$ lowers renewable costs
- A function of:
  - Cumulative R&D, $H_t$, requiring investment costs
  - Cumulative production (LBD), $Q_t$
  - Differs by technology
- Benefits are appropriated according to factor $\rho$
  - Spillovers present when $\rho < 1$
Nonrenewable generation

- **Profits** = discounted revenues less production costs and emissions and output tax payments
  \[
  \pi^i = n_1 \left( (P_1 - \phi^i)q^i_1 - C_{i1}(q^i_1) - \tau^i \mu^i q^i_1 \right) \\
  + \delta n_2 \left( (P_2 - \phi^i)q^i_2 - C_{i2}(q^i_2) - \tau^i \mu^i q^i_2 \right)
  \]

- **Emissions**: \(E_t = \mu^x q^x_t + \mu^{ng} q^{ng}_t\)

- **Conditions for profit maximization**:
  - Electricity price equals total marginal cost of fossil production, inclusive of emissions cost and fossil tax
    \[
    P_t = C'_{it}(q^i_t) + \phi^i_t + \tau^i \mu^i
    \]
  - Implies coal and natural gas produced until their marginal cost, inclusive of emissions cost, is equal
    \[
    C'_i(q_{it}) + \tau^i \mu_i = C'_j(q_{jt}) + \tau^j \mu_j
    \]
Renewable generation

- **Profits** = discounted revenues and subsidies, less production and R&D costs

\[ \pi^j = n_1 \left( (P_1 + s_1^j)q_1^j - G_1^j(K_1^j, q_1^j) - (1 - \sigma)R\left(h_1^j\right) \right) + \delta n_2 \left( (P_2 + s_2^j)q_2^j - G_2^j(K_2^j, q_2^j) \right) \]

- **Conditions for profit maximization**
  - Marginal cost = price received + appropriated value of LBD
    \[ G_q(K_1, q_1) = P_1 + s_1 - \delta \rho n_2 G_K(K_2, q_2) K_q(H_2, Q_2); \]
    \[ G_q(K_2, q_2) = P_2 + s_2; \]
  - Marginal cost of R&D knowledge = marginal value of corresponding appropriated cost reductions in 2nd stage
    \[ R_h(h_1) = -\delta \frac{\rho}{(1 - \sigma)} n_2 G_K(K_2, q_2) K_h(H_2, Q_2) \]
Consumers

- Maximize utility from electricity services, $v$, net of the costs of electricity consumption and EE improvements, $\theta$, after subsidies $b$

$$U = n_1 \left( u(v_1) - P_1 v_1 \psi_1^0 e^{-(\theta_1^s+\theta_1^L)} - (1-b_{s1})Z_{s,1}(\theta_1^S) - (1-b_L)Z_L(\theta_L) \right)$$

$$+ \delta n_2 \left( u(v_2) - P_2 v_2 \psi_2^0 e^{-(\theta_2^s+\theta_2^L)} - (1-b_{s2})Z_{s,2}(\theta_2^S) \right)$$

- EE improvements
  - Short-run (e.g., appliances) in each period
  - Long-run (e.g., buildings) in 1st period carry over
  - Increasing investment costs
  - Valuation rate for EE improvements, $\beta_j \leq 1$
    shows up in first-order conditions

$$\left( 1-b_{s_t} \right) Z_{s,t}'(\theta_t^S) = \beta_t^S P_D t; \quad \left( 1-b_{L} \right) Z_L'(\theta_L) = \beta_L^L P_D + \frac{n_2}{n_1} \beta_L^\delta P_2 D_2$$
Electricity Demand

- From first-order condition w.r.t. services
  \[ u'_t(v_t) = P_t \psi_t, \text{ and } D = \psi v \]

- Demand \[ D_t = N_t (\psi_1^0 e^{-(\theta_t^S + \theta_t^L)})^{1-\varepsilon} P_t^{-\varepsilon} \]
  is function of
  - Price
  - Rate of electricity consumption per unit of energy services, which is a function of
    - Short-run EE improvements
    - Long-run EE improvements
    - Very short-run elasticity
Net benefits and other impacts

- Solution defines prices, quantities of generation and R&D, cost reductions
- Net benefits equals sum of changes in:
  - Consumer surplus: $\Delta CS$
  - Producer surplus (profits): $\Delta \Pi$
  - Government transfers: $\Delta V$
  - Environmental benefits: $\Delta B$
  - Net benefits: $\Delta W = \Delta CS + \Delta \Pi + \Delta V + \Delta B$
Change in Welfare
Given an Emissions Target

- Changes in EE investments
  \[ dW = n_1P_1D_1 \left( \frac{(1 - \beta_1^S) - b_{s1}^L}{1 - b_{s1}^L} d\theta_1^S + \frac{(1 - \beta_1^L) - b_L}{1 - b_L} d\theta_L \right) \]
  \[ + \delta n_2P_2D_2 \left( \frac{(1 - \beta_2^L) - b_L}{1 - b_L} d\theta_L + \frac{(1 - \beta_2^S) - b_{s2}^L}{1 - b_{s2}^L} d\theta_2^S \right) \]

- Change in LBD

- Change in R&D

- Other costs

\[ + n_1 \left( \sum_{j=w,s} -\delta n_2 G^j (K_2^j, q_2^j)(1 - \rho)K_{Q_2} - s_j^i \right) dq_1^j \]

\[ + \delta n_1n_2 \sum_{j=w,s} -G^j (K_2^j, q_2^j)K_{H_2} \left( \frac{(1 - \rho) - \sigma}{1 - \sigma} \right) dh_1^j \]

\[ + n_1 \sum_{i=x,ng, cc,nu} \phi_i^i dq_1^i + \delta n_2 \sum_{i=x,ng, cc,nu} \phi_2^i dq_2^i - \delta n_2 \sum_{j=w,s} s_j^j dq_2^j \]
Optimal Policy is a Combination

1. Carbon price, rising according to the discount factor
2. Subsidies for early-stage LBD in the first stage to correct for learning spillovers for each technology
3. R&D subsidy equal to the R&D spillover rate
4. Subsidy to EE investments to offset the unvalued share of EE benefits, both in the short and long term
Numerical Application to U.S. Electricity Sector

- Simulations based on analytical model
- Linear supply curves
- Parameters and baseline values calibrated to EIA 2013 AEO
- Knowledge functions as in FN, based on available empirical R&D and learning literature
- Targeted demand elasticities to very short, short, and long-run estimates from literature
Baseline Generation

<table>
<thead>
<tr>
<th>kWh/year</th>
<th>2015-2019</th>
<th>2020-2040</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0E+00</td>
<td>5.0E+11</td>
<td>1.0E+12</td>
</tr>
<tr>
<td>5.0E+11</td>
<td>1.5E+12</td>
<td>2.0E+12</td>
</tr>
<tr>
<td>1.0E+12</td>
<td>2.5E+12</td>
<td>3.0E+12</td>
</tr>
<tr>
<td>1.5E+12</td>
<td>3.5E+12</td>
<td>4.0E+12</td>
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<tr>
<td>2.0E+12</td>
<td>4.5E+12</td>
<td>5.0E+12</td>
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<td>2.5E+12</td>
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<td>3.0E+12</td>
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<td>3.5E+12</td>
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<td>4.0E+12</td>
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<tr>
<td>4.5E+12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.0E+12</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Solar: 0.8% in 2015-2019, 1.1% in 2020-2040
- Wind etc: 6.2% in 2015-2019, 7.5% in 2020-2040
- Hydro: 2015-2019, 2020-2040
- Nuclear: 2015-2019, 2020-2040
- Nat Gas: 2015-2019, 2020-2040
- Oil: 2015-2019, 2020-2040
- Coal: 2015-2019, 2020-2040
Supply Curves in the Baseline

Rate of cost reduction:
- 29% for solar,
- 7% for wind

Price:
\[ P_1^0 = 0.093 \]
\[ P_2^0 = 0.098 \]
## No-Policy Baseline

<table>
<thead>
<tr>
<th></th>
<th>Stage 1</th>
<th>Stage 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price of electricity ($P_t$) (¢/kWh)</td>
<td>9.3</td>
<td>9.8</td>
</tr>
<tr>
<td>Electricity demand ($D_t$) (kWh/yr)</td>
<td>$4.26 \times 10^{12}$</td>
<td>$4.78 \times 10^{12}$</td>
</tr>
<tr>
<td>Coal generation ($q_t^c$) (kWh/yr, % of generation)</td>
<td>$1.59 \times 10^{12}$, 37.3%</td>
<td>$1.76 \times 10^{12}$, 36.8%</td>
</tr>
<tr>
<td>Oil generation ($q_t^{oil}$) (kWh/yr, % of generation)</td>
<td>$1.82 \times 10^{10}$, 0.4%</td>
<td>$1.78 \times 10^{10}$, 0.4%</td>
</tr>
<tr>
<td>Natural gas generation ($q_t^{ng}$) (kWh/yr, % of generation)</td>
<td>$1.19 \times 10^{12}$, 27.9%</td>
<td>$1.38 \times 10^{12}$, 28.9%</td>
</tr>
<tr>
<td>Nuclear generation ($q_t^{nu}$) (kWh/yr, % of generation)</td>
<td>$8.56 \times 10^{11}$, 20.1%</td>
<td>$8.95 \times 10^{11}$, 18.7%</td>
</tr>
<tr>
<td>Hydro generation ($q_t^{h2o}$) (kWh/yr, % of generation)</td>
<td>$3.09 \times 10^{11}$, 7.3%</td>
<td>$3.15 \times 10^{11}$, 6.6%</td>
</tr>
<tr>
<td>Wind generation ($q_t^{w}$) (kWh/yr, % of generation)</td>
<td>$2.64 \times 10^{11}$, 6.2%</td>
<td>$3.58 \times 10^{11}$, 7.5%</td>
</tr>
<tr>
<td>Solar generation ($q_t^{s}$) (kWh/yr, % of generation)</td>
<td>$3.53 \times 10^{10}$, 0.8%</td>
<td>$5.37 \times 10^{10}$, 1.1%</td>
</tr>
<tr>
<td>CO$_2$ emissions ($E_t$) (billion metric tons CO$_2$/year)</td>
<td>2.05</td>
<td>2.30</td>
</tr>
<tr>
<td>Rate of wind cost reduction (%)</td>
<td>7%</td>
<td>—</td>
</tr>
<tr>
<td>Rate of solar cost reduction (%)</td>
<td>29%</td>
<td>—</td>
</tr>
<tr>
<td>Policy Results</td>
<td>Emissions price alone</td>
<td>Optimal policy combination</td>
</tr>
<tr>
<td>--------------------------------------</td>
<td>-----------------------</td>
<td>----------------------------</td>
</tr>
<tr>
<td></td>
<td>No EE failures</td>
<td>10% EE undervaluation</td>
</tr>
<tr>
<td>Emissions reduction target</td>
<td>40%</td>
<td></td>
</tr>
<tr>
<td>Emissions price, stage 1 ($τ_1$) ($/ton CO_2$)</td>
<td>13.67</td>
<td>11.64</td>
</tr>
<tr>
<td>Emissions price, stage 2 ($τ_2$) ($/ton CO_2$)</td>
<td>34.73</td>
<td>29.58</td>
</tr>
<tr>
<td>Learning subsidy (wind) 1 (¢/kWh)</td>
<td>0.70</td>
<td>0.64</td>
</tr>
<tr>
<td>Learning subsidy (solar) 1 (¢/kWh)</td>
<td>4.93</td>
<td>4.54</td>
</tr>
<tr>
<td>R&amp;D subsidy (wind)</td>
<td>50%</td>
<td>50%</td>
</tr>
<tr>
<td>R&amp;D subsidy (solar)</td>
<td>50%</td>
<td>50%</td>
</tr>
<tr>
<td>EE subsidy, stage 1 ($b_{S1}, b_{L1}$)</td>
<td>0%</td>
<td>10%</td>
</tr>
<tr>
<td>EE subsidy, stage 2 ($b_{S2}, b_{L1}$)</td>
<td>0%</td>
<td>10%</td>
</tr>
<tr>
<td>Electricity price, stage 1 (% change from baseline)</td>
<td>13.6%</td>
<td>11.5%</td>
</tr>
<tr>
<td>Electricity price, stage 2 (% change from baseline)</td>
<td>23.8%</td>
<td>18.7%</td>
</tr>
<tr>
<td>% Non-hydro renewables, stage 1</td>
<td>9.8%</td>
<td>10.9%</td>
</tr>
<tr>
<td>% Non-hydro renewables, stage 2</td>
<td>19.8%</td>
<td>22.1%</td>
</tr>
<tr>
<td>% EE improvement, stage 1</td>
<td>3.9%</td>
<td>3.2%</td>
</tr>
<tr>
<td>% EE improvement, stage 2</td>
<td>8.1%</td>
<td>6.5%</td>
</tr>
<tr>
<td>Δ Welfare (billion $, annualized)</td>
<td>-10.12</td>
<td>-6.99</td>
</tr>
<tr>
<td>%W improvement (from emissions price alone)</td>
<td>_</td>
<td>16%</td>
</tr>
</tbody>
</table>
## Single Policy Levels to Achieve 40% Reduction

<table>
<thead>
<tr>
<th>Stage</th>
<th>Emissions Price ($/ton CO$_2$)</th>
<th>Emissions Performance Standard (ton CO$_2$/GWh)</th>
<th>Fossil Fuel Tax (¢/kWh)</th>
<th>Clean Energy Standard (%)</th>
<th>Renewable Portfolio Standard (%)</th>
<th>Renewable Production Tax Credit (¢/kWh)</th>
<th>EE Subsidy (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 1</td>
<td>13.67</td>
<td>409</td>
<td>1.45</td>
<td>53.8</td>
<td>11.2</td>
<td>3.10</td>
<td>33% short run 63% long run</td>
</tr>
<tr>
<td>Stage 2</td>
<td>34.73</td>
<td>285</td>
<td>3.67</td>
<td>69.3</td>
<td>31.1</td>
<td>7.87</td>
<td>33%</td>
</tr>
</tbody>
</table>

Like emission price + generation subsidy

Like subsidy to qualifying sources + generation tax
Relative policy costs with EE undervaluation

![Chart showing relative policy costs with and without EE undervaluation for different policies including EPS, FossilTax, CES, RPS, PTC, EE subsidy, and Optimal. The x-axis represents the policies, while the y-axis shows the welfare cost relative to emissions price. The chart compares costs under ‘No EE undervaluation’ and ‘10% EE undervaluation.’]
Second-Best Combination Policies: RPS

- RPS that maximizes welfare with an emissions cap is only 1–2% pts above reference scenario
  - Learning externality relatively small
- Exacerbates EE undervaluation, since modest RPS lowers electricity prices
  - With 10% undervaluation, no RPS improves cost-effectiveness
Second-Best Combination Policies: EE Standards

- With no undervaluation, welfare decreasing
  - Also because it lowers electricity prices, exacerbating the knowledge market failure
- With 10% undervaluation, second-best EE standards close to the optimal improvements
  - But the required subsidies are lower, due to the absence of the renewable energy technology policies, which would otherwise keep electricity prices lower.
More Ambitious Combinations

- 40/20/10 policy
  - 40% emissions reduction
  - 20% RPS
  - 10% improvement in EE

- Binding in both stages
Sensitivity of Cost of Cap versus Combination Targets to EE Undervaluation
Sensitivity of Cost of Cap versus 20/20/20 Targets to Knowledge Spillovers
Sensitivity of Optimal First-Stage Policies to Emissions Target

- Optimal wind subsidy
- Optimal solar subsidy
- Optimal emissions tax (right axis)

Percentage reduction in emissions

- $/ton CO2
- cents/kWh

Optimal wind subsidy Optimal solar subsidy
Optimal emissions tax (right axis)
Variations

- Double credits for solar lowers costs somewhat but not substantially
- Optimal R&D policy cuts costs in half
Decomposing the Welfare Gains from Renewable Technology Policies

(No Policy Baseline)

- Correcting LBD externality alone: <20%
- Correcting R&D externality alone: 1%
- Additional gains when correcting both: >80%
Optimal subsidies

![Bar chart showing optimal subsidies for Wind and Solar with different scenarios: No EE undervaluation, 10% EE undervaluation, and Optimistic parameters.](image-url)
Caveats and Extensions

- We have not included other market failures
  - values for energy security or supply diversification.
  - infrastructure requirements, barriers to entry, economies of scale, imperfect competition,
  - damages from other pollutants that may not be internalized.

- Role of political constraints on emissions pricing
  - Lowering carbon prices can address industrial competitiveness concerns
  - Overlapping policies can mask true costs
Distributional Effects

Cap-and-Trade alone (CAT)
“40/20/10” Policy: CAT + RPS + EE
"Technology only": RPS + R&D + EE
Optimal

Consumers
Taxpayers
Renewable Energy
Fossil Energy
Nuclear and Hydro
Total Surplus Change
Conclusions

- Some technology policies can complement emissions pricing for reducing GHGs when additional market failures are present.
- However, these justifiable policies are likely to be much more modest than the suite of renewable energy policies being proposed.
  - Even with high rates of knowledge spillovers from learning by doing, ambitious RPSs seem unlikely to be welfare enhancing.
  - Correcting R&D market failures has greater potential for reducing costs.
Conclusions (2)

- The desirability of stringent EE policies very sensitive to the degree of undervaluation.
  - Priority for empirical work
- Even with more refined representations of electricity markets & failures, emissions pricing still the single most cost-effective option
- Technology policies are very poor substitutes, and when they overreach, they can be poor complements too.
The Future of Overlapping Strategies

"...and each of the 45 nuclear reactors will have a wind turbine on top and four solar panels surrounding it!..."
Thanks!

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